SPECIFICATION

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METHOD FOR OPTIMIZING STRATEGY FOR ELECTRIC MACHINES

Background of Invention

[0001] This invention relates generally to electric machines and, more particularly, to an optimization strategy for designing induction motors and generators.

[0002] Known motors including synchronous machines, non-synchronous machines, and direct current (DC) machines, include a motor housing, a stator including one or more windings, or one or more permanent magnets, and a rotor assembly. The rotor assembly includes a rotor core and a rotor shaft that extends through the rotor core. The rotor is constructed of a plurality of laminations and includes one or more armature windings one or more permanent magnets. The motor housing includes at least one endshield and houses at least a portion of the rotor assembly. At least one bearing receives and the rotor shaft, and is positioned between the endshield and an inner bearing cap to enable the rotor shaft to rotate during operation.

[0003] At least some known motors are configured to satisfy pre-determined steady state operating requirements such as a rated voltage, a locked rotor voltage, and a breakdown voltage. Two key components for satisfying operating requirements are lamination geometry and winding variables. The lamination geometry and winding variables are configured to facilitate optimizing performance cost variables associated with the motor design. At least some known design methods attempt to optimize a winding after a lamination design is know. This design method may only provide acceptable results the bounds of the particular lamination, and as such, does not allow the assertion that a global optimum has been found. Other known methods attempt to simultaneously optimize all the winding variables and lamination geometry variables. This design is much more complex and computationally expensive.

Summary of Invention

[0004] In one aspect, a method is provided to facilitate optimizing a winding and lamination configuration of an electric machine. The method employs a computer including a microprocessor for executing computer functions, a database for storing optimization data, and a two-level optimization algorithm that has a first optimization module and a second optimization module. The method includes generating a plurality of data sets utilizing the first module, determining an optimum response surface based the data sets, utilizing the second module, determining an optimum data set based on the optimum response surface, utilizing the first module, and outputting an optimum winding and lamination configuration based on the optimum data set.

[0005] In another aspect, a system is provided for optimizing a winding and lamination configuration of an electric machine. The system includes a computer including a microprocessor for executing computer functions, a database coupled to the microprocessor for storing data, and a two-level optimization algorithm comprising a optimization module and a second optimization module. The two-level optimization algorithm uses data stored in the database and is executed via the microprocessor.

[0006] In yet another aspect, a two-level optimization algorithm is provided for optimizing a winding and lamination configuration of an electric machine. The two-level optimization algorithm includes a first optimization module and a second optimization module. The optimization module is configured to generate a first optimization solution based on output from the second optimization module, and the second optimization is configured generate a second optimization solution based on output from the first optimization module. Furthermore, the two-level optimization algorithm is also configured to generate a global optimization solution based on the first and second optimization solutions.

Brief Description of Drawings

[0007] Figure 1 is schematic of a system to facilitate optimizing a winding-lamination configuration of an electric machine.

[0008] Figure 2 is an exemplary embodiment of a detailed diagram of a two-level algorithm utilized by the system shown in Figure 1.

[0009] Figure 3 is an alternate embodiment of a detailed diagram of a two-level algorithm utilized by the system shown in Figure 1.

[0010] Figure 4 is a simplified block diagram of a server architecture used with the system shown in Figure 1 for facilitating optimizing a winding-lamination configuration.

[0011] Figure 5 is an expanded version block diagram of an alternate embodiment of a architecture for facilitating optimizing a winding-lamination configuration.

Detailed Description

[0012] Figure 1 is schematic of a system 10 to facilitate optimizing a winding a lamination configuration of an electric machine in accordance with one embodiment of the present invention. System 10 includes a computer 14, which includes a processor 18 suitable to execute all functions of computer 14, and an electronic storage device, or database, 22 storing programs, information and data. Additionally, computer 14 is connected to a display 26 for displaying information, data, and graphical representations, and a user interface 30 that enables a user to input information, data, and queries to computer 14, example a keyboard or a mouse. In the exemplary embodiment, computer 14 also a second electronic storage device 34, which stores an optimization algorithm 38. Optimization algorithm 38 implements a two-level optimization strategy that includes a winding optimization level and lamination optimization level. Accordingly, algorithm 38 includes a first module, such as winding optimization module 42 and a second module, such as lamination optimization module 46. In an alternate embodiment algorithm 38 is included within database 22. Two-level optimization algorithm 38 links a solution for an optimal lamination, computed at the lamination optimization level by lamination module 46, to a solution for an optimal winding, computed at the winding level by winding 42.

[0013] Two-level optimization algorithm 38 processes small sets of variables at both the winding optimization level and the lamination optimization level. Additionally, solutions computed by modules 42 and 46 are decomposed such that more autonomy is given to lamination and winding designers, while at the same time taking into account both and lamination preferences.

[0014]

Figure 2 is an exemplary embodiment of a detailed diagram of two-level optimization algorithm 38 (shown in Figure 1) utilized by system 10 (shown in Figure 1). Components Figure 2 identical to components of system 10 of Figure 1 are identified in Figure 2 using the same reference numerals as used in Figure 1. Database 22 (shown in Figure 1)

winding parameters, including but limited to, wire size, number of turns, capacitor size, frame size, number of windings, and number of coils. Winding optimization module 42 utilizes a mathematical programming model for winding level that includes motor level variables, including but not limited to, winding material, i.e. copper or aluminum wire, capacitor size, motor housing size, frame size, number of windings, number of coils and wire size. Lamination module 46 utilizes a mathematical programming model for lamination level optimization that has continuous and discrete lamination geometry variables. Continuous lamination geometry variables, such as slot thickness, inner diameter, outer diameter and slot spacing, are variables that have an open set of values. For example, the slot thickness variable can be chosen to be 0.325 inches, or 1.0 inches, or 1.8 inches, or any number there between. Discrete lamination variables, such as sheet thickness, are variables that have a closed set of values. For example, possible sheet thickness values may only be values selected from available manufactured thicknesses.

[0015] A designer utilizes interface 30 (shown in Figure 1), to input two sets of performance constraints. The first set of performance constraints relate to lamination geometries such as a number of lamination layers, and lamination size. The second set of performance constraints are determined by desired performance requirements, such as, but not to, motor size, efficiency, power output, cost, torque, current, current density, and motor speed. After the performance constraints are input, winding optimization module 42 utilizes the winding parameters stored in database 22 to compute and output a plurality solutions, or data sets, for the winding level optimization mathematical programming model. The plurality of solutions output are solutions of the winding level optimization mathematical programming model using different possible combinations of winding parameters and motor level variables. Thus, winding optimization module 42 varies both the motor level variables and the winding parameters used by the winding level optimization mathematical programming model to compute a plurality of different winding configurations.

[0016] The possible winding configurations are output to lamination module 46 wherein the winding configurations are used to solve the lamination level optimization mathematical programming model. Lamination module 46 computes an optimum lamination geometry configuration for each winding configuration output from winding module 42. Lamination optimization module 46 uses outputs from winding optimization module 42 and lamination geometry variable data stored in database 22, including machinability data, to

compute a lamination geometry that will combine with each respective winding module output to satisfy at least one constraint of the first set of performance constraints input a designer. Each lamination geometry is then output to database 22. Lamination module 46 then utilizes the lamination geometries stored in database 22 and the second set of performance constraints to determine an optimum geometry response surface. The optimum geometry response surface includes the lamination geometries computed by lamination optimization module 46 that satisfy at least one of the constraints in the set of performance constraints.

[0017] The optimum geometry response surface is then output to winding optimization module 42 wherein at least one optimum winding solution, or data set, is computed. To compute the optimum winding solution, winding optimization module 42 varies the level variables and a corresponding optimum lamination for each variation is obtained the optimum geometry response surface to produce a candidate winding-lamination configuration. Algorithm 38 (shown in Figure 1) is then used to compute manufacturing objectives, such as cost and efficiency ratings for each candidate winding-lamination configuration. Each candidate winding-lamination configuration is then output, along the corresponding cost and performance values, and evaluated to determine a global, or optimum desirable, winding-lamination configuration. In one embodiment, the candidate winding-lamination configurations output by algorithm 38 are stored in a database such database 22.

[0018] Figure 3 is an alternate embodiment of a detailed diagram of two-level optimization algorithm 38 (shown in Figure 1) utilized by system 10 (shown in Figure 1). Components Figure 3 identical to components of system 10 of Figure 1 are identified in Figure 3 using the same reference numerals as used in Figure 1. Database 22 (shown in Figure 1) winding parameters such as wire size, number of turns, capacitor size, frame size, of windings, and number of coils. Database 22 also includes a list of standard manufactured laminations geometries and specific data relating to the characteristics of each lamination geometry, including but not limited to, slot thickness, sheet thickness, inner diameter, outer diameter, and slot spacing. Winding optimization module 42 a mathematical programming model to facilitate winding level optimization. The mathematical programming model utilizes motor level variables such as winding i.e. copper or aluminum wire, capacitor size, motor housing size, frame size, number of windings, number of coils and wire size. Lamination module 46 utilizes a mathematical

programming model for lamination level optimization having lamination geometry variables, such as slot thickness, inner diameter, outer diameter, slot spacing and sheet thickness.

[0019] A designer utilizes interface 30 (shown in Figure 1), to input two sets of performance constraints. The first set of performance constraints relate to lamination geometries such as a number of lamination layers, and a lamination size. The second set of performance constraints are determined by desired performance requirements, such as, but not to, motor size, efficiency, power output, cost, torque, current, current density, and motor speed. After the performance constraints are input, lamination optimization module 46 generates and outputs a plurality of solutions, or data sets, for the lamination level optimization mathematical programming model. The plurality of outputs solve for lamination geometries that satisfy at least one of the constraints in the first set of performance constraints. The plurality of lamination geometries generated is selected the standard manufactured lamination geometries stored in database 22.

[0020] The possible lamination geometries are output to winding optimization module 42 wherein the lamination geometries are used to solve the winding level optimization mathematical program model. Winding optimization module 42 utilizes the winding parameters motor level variables stored in database 22 to compute at least one optimum winding configuration for each lamination geometry that will combine with the lamination geometry to satisfy at least one constraint of the second set of performance constraints. Each winding configuration is then output to database 22. Winding module 42 then the winding configurations stored in database 22 to determine an optimum winding variable response surface for each lamination geometry output by lamination module 46. The optimum winding variable response surfaces include all the computed winding configurations for the related lamination geometry.

[0021] The optimum winding variable response surfaces are then output to lamination 46 wherein at least one optimum lamination solution, or data set, is computed. To compute the optimum lamination solution, lamination module 46 varies the lamination geometry variables and corresponding optimum winding variables are obtained from the optimum winding variable response surfaces to produce a candidate winding-lamination configuration for each variation. Subject to at least one constraint in the second set of performance constraints, algorithm 38 (shown in Figure 1) is then used to compute

manufacturing objectives, such as cost, magnetomotive force (MMF), efficiency rating, or combination of these, for each candidate winding-lamination configuration. Each winding-lamination configuration is then output, along with the corresponding cost and performance values, and evaluated to determine a global, or optimum desirable, lamination configurations. In one embodiment, the candidate winding-lamination configurations output by algorithm 38 are stored in a database such as database 22.

[0022] Figure 4 is a simplified block diagram of a server system 100 for optimizing a lamination configuration. In an alternative embodiment, computer 14 (shown in Figure 1) part of a computer network that is accessible using the Internet. System 100 includes a server system 112 and a plurality of client systems 114 connected to server system 112. one embodiment, client systems 114 are computers, such as computer 14 (shown in 1), including a web browser, such that server system 112 is accessible to client systems 114 via the Internet. Client systems 114 are interconnected to the Internet through many interfaces including a network, such as a local area network (LAN) or a wide area network (WAN), dial-in-connections, cable modems and special high-speed ISDN lines. Client systems 114 could be any device capable of interconnecting to the Internet including a web-based phone or other web-based connectable equipment. A database server 116 is connected to a centralized database 120 containing product related information on a variety of products, as described below in greater detail. In one embodiment, centralized database 120 is stored on server system 112 and can be accessed by potential users at of client systems 114 by logging on to server system 112 through one of client systems 114. In an alternative embodiment centralized database 120 is stored remotely from system 112.

[0023] Figure 5 is an expanded version block diagram of an alternate embodiment of a architecture 200 for optimizing a winding-lamination configuration, used in conjunction with the system shown in Figure 1. Components in system 200, identical to components system 100 (shown in Figure 4), are identified in Figure 5 using the same reference numerals as used in Figure 4. System 200 includes server system 212 and client systems 214. Server system 212 further includes database server 216, an application server 224, web server 226, a directory server 230, and a mail server 232. A disk storage unit 234 is coupled to database server 216 and directory server 230. Servers 216, 224, 226, 230, 232 are coupled in a local area network (LAN) 236. In addition, a system administrator"s workstation 238, a user workstation 240, and a supervisor"s workstation 242 are coupled

to LAN 236. Alternatively, workstations 238, 240, and 242 are coupled to LAN 236 via an Internet link or are connected through an Intranet.

[0024] Each workstation, 238, 240, and 242 is a personal computer, such as computer 14 (shown in Figure 1) having a web browser. Although the functions performed at the workstations typically are illustrated as being performed at respective workstations 238, 240, and 242, such functions can be performed at one of many personal computers coupled to LAN 236. Workstations 238, 240, and 242 are illustrated as being associated with separate functions only to facilitate an understanding of the different types of functions that can be performed by individuals having access to LAN 236.

[0025] In another embodiment, server system 212 is configured to be communicatively coupled to various individuals or employees 244 and to third parties, e.g., internal or external auditors, 246 via an ISP Internet connection 248. The communication in the exemplary embodiment is illustrated as being performed via the Internet, however, any other wide area network (WAN) type communication can be utilized in other i.e., the systems and processes are not limited to being practiced via the Internet. In addition, and rather than a WAN 250, local area network 36 could be used in place of 250.

[0026] In the exemplary embodiment, any authorized individual or an employee of the business entity having a workstation 254 can access the locomotive management system. One of the client systems includes a workstation 256 located at a remote location. Workstations 254 and 256 are personal computers having a web browser. Also, workstations 254 and 256 are configured to communicate with server system 212.

[0027] While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with within the spirit and scope of the claims.